38. *On the* ORIGIN *of some* HANGING VALLEYS *in the* ALPS *and* HIMALAYAS. By Prof. E. J. GARWOOD, M.A., F.G.S. (Read June 11th, 1902.)

(PLATES XXXVI–XL.)

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I. INTRODUCTION.

DURING my visit to the Eastern Himalayas in 1899, I was much struck by the discordance of certain of the tributary valleys to the main valleys which they feed in the district of Jongri, near the south-eastern foot of Kabru. While making a plane-table survey of this district, I arrived at certain conclusions with regard to the origin of these valleys, which I have already published in the journal of a kindred Society.[1] I was, therefore, much interested when my attention was drawn to a paper by Prof. W. M. Davis on 'Glacial Erosion in the Valley of the Ticino,'[2] in which the hanging valleys in the lower part of the Val Ticino are attributed to the over-deepening of the main valley by ice. His theory of their origin may be briefly stated in the following paragraph taken from the paper above cited:—

> 'The deepening of a glaciated valley for a good part of its length is thus seen to be a general result of glacial erosion; it is accompanied throughout by discordant or hanging lateral valleys, and the production of a lake in the distal portion of such a valley is but a subordinate result of glacial action.' (*Op. cit.* p. 152.)

This theory of the origin of hanging valleys is diametrically opposed to the one at which I had arrived, from a study of similar valleys in the Sikhim Himalayas. Coming as it does, however, from one of our foremost exponents of drainage-problems, it deserves most careful consideration.

I propose, therefore, first to consider all the evidence available with regard to the possible modes of formation of the hanging valleys which occur in the Val Ticino itself, and afterwards to bring to bear on the question any evidence from similar phenomena in other districts, with which I am acquainted, which may tend to throw light on the origin of the Ticino valleys.

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[1] Geogr. Journ. vol. xx (1902) p. 13.

[2] 'Appalachia' vol. ix (1900) pp. 136-56 w. figs. & pls. xv–xvi.

In the first place, I feel that I owe to Prof. Davis an apology for entering as a critic into a field of research which he has made so peculiarly his own. I should like to urge, however, as an extenuating circumstance that, though I have written little, I have lived a large portion of my life among the glaciers of the Alps, and in particular in the neighbourhood of the St. Gotthard range. Had Prof. Davis selected any other district but the Val Ticino, I should most likely not have considered myself justified in criticizing his facts and conclusions; but with the Val Ticino I have had a long and intimate acquaintance, having traversed it on an average twicea year for upwards of twenty years, either on foot, in coach, or by train, and have a personal knowledge of nearly every gully and lake between Airolo and the Lago Maggiore.

Under these circumstances, I feel bound to suggest an alternative origin, for the discordant lateral valleys which Prof. Davis has described, from that which he has advocated—a theory as to their origin which has been considerably strengthened by a study of the hanging valleys which I have met with in Sikhim and elsewhere.

II. Hanging Valleys of the Val Ticino.

To the accuracy of the facts stated in Prof. Davis's excellent description of the main features of the Val Ticino between Giornico and Biasca I can fully testify. The basal cliffs, the gentler slope forming benches above, and the open character of the valley below Biasca are familiar features; and I quite agree with him that

> 'the benches seem to be the remnants of the slower slopes of an ancient wide-open valley, in whose floor the present cliff-walled deeper valley has been eroded; and this supposition is confirmed when it is found that the high-standing lateral valleys are systematically related to the ancient rather than to the modern valley-floor.' (*Op. cit.* p. 146.)

But when we come to the statement (*op. cit.* p. 147) that

> 'The famous corkscrew tunnels . . . . are therefore to be regarded, along with the stone posts of the grape-arbours in the vineyards about Biasca, as indirect consequences of glacial action,'

we have reached the gist of the matter, and I must join issue; for I cannot admit that this assumption of the over-deepening of the lower portion of the valley by direct ice-erosion is at all borne out by the facts of the case, even if we adopt Prof. Davis's own line of argument, although, as I shall endeavour to show, ice has, in my opinion, been probably the indirect cause of the formation of the hanging valleys, but in a very different manner from that advocated by Prof. Davis.

Let us review the evidence brought forward to support the theory that the lower portion of the main valley below the benches and below the mouths of the hanging valleys has been entirely excavated by ice. This evidence rests on two facts: (1) the steep character of the main-valley wall below the level of the hanging valleys; and (2) the absence of

> 'overlapping profiles, entering the valley from one side and the other alternately, and concealing the more distant parts of the valley-floor.' [1]

The first of these arguments does not by itself afford any evidence of overdeepening by ice, as we have plenty of instances of river-gorges with inaccessible sides and subparallel walls. No one, for instance, imagines that the cañons of Colorado or the gorge of the Via Mala owe their origin to overdeepening by ice; and this Prof. Davis would be the first to admit. It is, therefore, on the second statement—that the characteristic 'crossing spurs' are absent from the Val Ticino—that the ice-excavation theory relies, supported by the presence of the hanging valleys and the steeper grade of the main-valley walls beneath.

Now, the hanging valleys described by Prof. Davis are all situated a short distance above or below Biasca, and his description of the valley's characteristics is entirely drawn from this portion of the Val Ticino. The valleys below Biasca are complicated by the results of the additional drainage from the Val Blenio; and as the portion above Biasca contains three of Prof. Davis's typical valleys, namely, the Val d'Ambra, the Val Nadro, and the Val Cramosina, I propose to confine myself to a description of the features of the Valle Leventina between Airolo and Biasca. For here we have but one main valley, running between two parallel ranges, which receives no sudden access of drainage at any portion of its course, the conditions under which any of its features were produced being consequently the same throughout.

If we examine the entire length of this valley, we find that the hanging valleys are by no means confined to the three just above Biasca, before mentioned, but occur at intervals right up to Piotta, 3 miles below Airolo, where the torrent of La Foos [2] plunges from the lake of Ritom in the Val Piora, by far the largest hanging valley in the district. Farther up again, the Val Tremola, draining the St. Gotthard Pass, though partly cut back, comes under this category; and higher still, in the Val Bedretto, the trench-like appearance of the valley and the precipitous character of the lateral streams are very marked features for a considerable distance. Among others, I may cite the Val Piumogna opposite Faido, and the Val Chironico above Giornico. Both of these are every whit as discordant in their relation to the Valle Leventina as those mentioned near Biasca, and whatever theory we adopt as to the mode of formation of one must apply equally to all.

I do not wish here to discuss the faulted character of the valley-floor above Faido, as I do not think that this has influenced the formation of hanging valleys, except to hasten the deepening of main valleys, especially perhaps above Airolo where the softer Jurassic beds have been let in.

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[1] See Prof. Davis's paper, 'Glacial Erosion in the Valley of the Ticino' Appalachia, vol. ix (1900) p. 142.

[2] Misprinted 'Foss' on the section and map, Pl. XXXVI.

A glance at the accompanying map (Pl. XXXVI) shows that, although the valley between Biasca and Giornico is fairly open, this is by no means the case above the latter village; and, instead of the trough-like character described by Prof. Davis as typical of a valley overdeepened by ice, we have exactly the features shown in fig. 1 of his paper[1] as characteristic of a water-cut valley, spur after spur overlapping in the distance, while the river winds sharply between its rocky walls. Thus, through Monte Piottino, the valley makes a double rectangular turn, necessitating two of the famous spiral tunnels above Faido, and similar overlapping profiles occur near Lavorgo, below Faido (see Pl. XXXVII, figs. 1 & 2, and explanation). Between these points, immediately opposite Faido, lies the hanging valley of Piumogna. Higher up again, nearer Airolo, we have two undoubted river-gorges, near Madrano and Brugnasco respectively, the former being so cañon-like in character that for both road and railway it has been necessary to resort to tunnelling (Pl. XXXIX, fig. 1).

We see, then, that the Valle Leventina shows all the features typical of a valley excavated by water, especially as regards the steeper basal trench represented in fig. 3 of Prof. Davis's paper.[2] The more open portion, near Biasca, presents no features inexplicable by ordinary river-erosion, and the width of its floor is undoubtedly increased by the deposition of shingle washed down from the upper valley, giving a much flatter character to the section than it would otherwise possess. The only abnormal features, therefore, are the hanging valleys, and these occur equally in the upper portion of the Valle Leventina, where (as we have seen) sections of the basal trench of the main valley between them are undoubtedly river-gorges as shown above. There is, then, no direct evidence that the overdeepening of the main valley, which has resulted in the production of the discordant lateral valleys, is due to erosion by ice; and it remains to account for the presence of these valleys by the ordinary process of river-excavation.

Now, all that would be required to produce the discordance in question would be an acceleration of the main Ticino River without a corresponding acceleration of its tributaries. This would immediately be produced were an elevation to take place at the upper end of the Val Ticino, whereby the grade of the valley should be perceptibly increased, while the lateral valleys were merely tilted sideways. That such an elevation has taken place I have, for some time past, considered as the only explanation possible of certain other phenomena in the district. Most of these do not directly bear on the subject in hand, although I think that the hanging valleys are but incidents connected with much larger problems of drainage on the southern side of the Alps, of which the formation of the Italian lakes constitutes an integral part.

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[1] 'Glacial Erosion in the Valley of the Ticino' Appalachia, vol. ix (1900) p. 142.

[2] *Ibid.* p. 146.

There are, however, three important facts which bear directly on the point at issue. The first of these is the striking manner in which many of the lateral tributaries enter the Ticino by gorges which point up stream. It was when seeking a solution of this curious phenomenon, that the idea of an elevation of the upper end of the district first occurred to me as the only possible explanation of the tilting of these gorges from their original vertical position. Another significant fact is the manner in which the drainage of the Val Piora has collected at its lower end to form Lago Ritom; and the third is the past history of the drainage of the Val Piumogna, opposite Faido.

The question of the origin of the group of lakes in the neighbourhood of the Val Piora is one which I must leave till another occasion; but it seems probable that, should an elevation of the upper end of the Val Ticino have taken place as postulated, there would be a tendency for the drainage to collect at the lower end of the Val Piora, until such time as a gorge should be cut down to a sufficient depth to drain off the accumulated water. That this result would be indefinitely delayed may be expected, when we remember that, on the first formation of the lake, all the transported fragments by which the work must be effected would be deposited at the upper end of the lake to form the delta on which the farm-buildings of Campo now stand, and only clear water would lap over into the old channel: the resulting fall has gradually cut back a gorge in the old valley below, but has not, as yet, appreciably affected the level of the lake above.

The direction of the ancient drainage of the Val Piumogna is another instance bearing on this question. In former times, the river appears to have drained westward from the hamlet of Dalpe by Prato, entering the Ticino where Morasco now stands, being headed off by the rocks of Monte Piottino so as to enter the Ticino up stream. This old depression is a conspicuous feature, and was the line followed by the old Roman road which climbed over Monte Piottino, past Prato and Cornone, to avoid the river-gorge below. After the elevation, the river was diverted to the east at right angles to its former course, and now falls in a series of cascades into the Ticino opposite Faido; the relics of the lake thus formed are seen in the deposit of alluvium in the valley above the fall.[1]

The questions now remain, When did this elevation take place? and to what was it due?

One point seems perfectly clear, namely, that it originated at all events before the last occupation of the valley by ice. This is shown, not only by the polished sides of the overdeepened portion of the main valley, but also by the rounded edges of the hanging valleys where these debouch into the Valle Leventina. The steep rock-walls on the western bank of the Ticino below Faido, however, are deceptive in this respect: the smooth slabs over which the rivulets cascade, which at first sight seem to point to great glacial erosion, are in reality due to planes of foliation in the gneiss. This is proved by the manner in which many of these smooth surfaces pass under the overlying slabs, while the truncated edges of these beds are sharp and angular, although they face up stream. In many cases, also, as under Calonico Church, the recent rock-falls from the surface of these slabs can be seen below.

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[1] See K. von Fritsch, 'Geognostische Karte des Sanct Gotthard' Beitr. z. Geol. Karte d. Schweiz, vol. xv (1873).

This elevation may possibly have been initiated in pre-Glacial times as a final stage in the orogenic uplift in the late Pliocene Period. I, however, incline to the belief that the hanging valleys were produced during the warmer inter-Glacial Periods, the existence of which in the Alps, first suggested fifty-five years ago by Collomb, has been now clearly demonstrated by the researches of James Geikie, Penck, Blaas, Bœhm, and others. Thus Prof. Penck[1] attributes an excavation of 720 feet in the valley of the Iller to river-erosion, during the mild period antecedent to the last advance of the Iller Glacier.

So far as I am aware, no lignite-deposits of this age have been recorded from the Val Ticino; but should any occur, I would expect to find them on the upper benches above Faido, between Mairengo and Calpiogna, and on the corresponding plateau between Dalpe and Prato. Possibly the lake-deposits mentioned above might contain remains of this inter-Glacial flora, while the presence of a fragment of a lower bench at 816 metres may indicate a succession of at least two former valley-floors.

One fact which seems to be more and more clearly established every year, is the tendency shown by all glaciated districts to undergo elevation as their covering of ice melts away. I need only recall the raised beaches of Spitsbergen, Franz-Josef Land, Norway, and North America, leaving out of account for the moment the Himalayas and the Alps themselves. One of the most interesting points recorded in a recent report of the Norwegian Geological Survey, is the coincidence of the greatest post-Glacial rise with the area of the greatest depression below the axis of the inland ice.[2] If this rise be accepted also for the Alps, after the maximum period of glaciation was passed, we have at once a solution of the problem of the hanging valleys. As the ice melted back, torrents of water would be discharged from the fronts of the retreating glaciers, and, as the country rose, the main river would rapidly deepen its valley, while the lateral valleys would not only remain at their former grade, but would also continue to be occupied for some time longer by ice—a fact well illustrated in the Alps nowadays. The hanging valleys thus initiated would be prevented from immediately establishing an accordant grade with the main valley; and the longer their glaciers remained, the longer would this result be delayed: only the mouth of the valley being cut back into a gorge by the water flowing from the glacier, while the curve of erosion of the gorge would flatten gradually as the ice retreated.

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[1] Jahresb. d. Geogr. Gesellsch. München, 1886, pt. ii. See also Penck & Brückner, 'Die Alpen im Eiszeitalter' Leipzig, 1901–02; A. Rothpletz, 'Ein geologischer Querschnitt durch die Ost-Alpen' Munich, 1894; & A. P. Coleman, Geol. Mag. 1902, p. 59.

[2] Norges Geol. Undersög. No. 28 (1900); & N. O. Holst, Sveriges Geol. Undersökn. ser. C, No. 180 (1899) p. 113.

On this supposition, then, those lateral valleys which have been longest freed from their protective covering of ice should have established the most accordant grade with the main valley; and this indeed we find to be the case. There are no true hanging lateral valleys remaining on the left bank of the Ticino, which faces west and south (with the exception of the Val Piora, the preservation of which has been already explained), while those found on the right wall face north and east, and it is in these that the ice will have been the last to melt: the head of the Val Piumogna being still occupied by a glacier.

In this way we see how ice could be indirectly responsible for the hanging valleys, and how we can explain their marked occurrence in glaciated regions, without attributing, as Prof. Davis has done, the overdeepening of the main valleys to direct erosion by ice.[1]

Before referring to the support that this explanation appears to receive from other districts, I would point out that there is one piece of evidence which seems strongly to favour the contention that the overdeepened floor of the Val Ticino was effected by water-erosion, and not by ice. If we attribute the overdeepening to ice-erosion, the action of the glacier should have been more marked at the lower end of the valley, near Biasca, than in the middle portion, near Airolo.[2] If, on the other hand, the overdeepening be due to an acceleration of the velocity of the river consequent on the elevation of the upper end of the district, we should expect the results to be greatest in the middle portion, and less marked at the lower end of the valley where the effects of elevation died away.

If, now, we construct a section along the present floor of the Val Ticino, from Airolo to Biasca, and restore the old floor before the overdeepening took place, using for this purpose the present position of the mouths of the hanging valleys between Airolo and Biasca, we find that there is a regular decrease in the respective heights of the hanging valleys, above the present thalweg of the Ticino, showing that the greatest amount of excavation has taken place in the floor of the old valley in its middle portion, and that the amount of overdeepening gradually decreases in the lower portion.[3] The heights are approximately shown on the accompanying diagram, drawn to the true scale of 1 : 50,000 (Pl. XXXVI, longitudinal section along the Valle Leventina). This appears to me conclusive evidence in favour of water having been the chief agent of erosion, and not ice. The Val Ticino, therefore, does

[1] Reusch, Norges Geol. Undersög. No. 32 (Aarbog for 1900).

[2] Prof. Davis attributes the excavation of the Lago Maggiore below to ice-erosion.

[3] It is here also that marked deposition commences.

not (in my opinion) furnish any evidence that the overdeepening of the main valley, and the consequent formation of hanging lateral valleys, has been due to the direct action of ice. On the contrary, the facts appear to point to the deepening of the old Ticino valley by water, consequent upon an epeirogenic uplift of the upper end of the district in inter-Glacial times.[1]

Although the evidence adduced in the foregoing pages appears to me conclusive, I am acquainted with two other districts exhibiting the characteristic features of hanging valleys which strongly confirm this view. The first is the Val Bregaglia, the second the Jongri district of the Sikhim Himalayas.

III. Hanging Valleys of the Val Bregaglia.

At the upper end of the Val Bregaglia, in close proximity to the Maloggia Pass, we have three hanging valleys in different stages of development—the Albigna, the Val Marozzo, and the gorge of the Orlegna, which drains the Forno Glacier and the Valley of La Tajeda. The Albigna Valley is occupied throughout its upper portion by the Albigna Glacier; but a short level tract of ground strewn with alluvium intervenes, between the end of the glacier and the cascade by which the water from the melting ice plunges into the gorge of the Pian dei Buoi below. No one who has ascended this gorge is likely to forget the severe character of the ascent, nor the detour necessitated by the precipitous nature of the fall: it is in every respect similar to the ascent to Dalpe from Faido, and the traveller is forcibly reminded of the Val Piumogna, in the Ticino Valley.

That this precipitous descent from the Albigna Glacier to Casaccia is due to the overdeepening of the main valley, has not, I think, been denied; and there can be little doubt that it has been effected by the vigorous encroachment of the Maira, on the water-parting between the Val Bregaglia and the Upper Engadine. If this water-parting were once situated farther down the Val Bregaglia, nearer Vico Soprano, as has been suggested,[2] the Albigna and Forno valleys on the south, and the Val Marozzo on the north, must once have formed tributaries of the Inn, and not of the Maira; and this supposition is borne out by the general trend and present relative elevation of these valleys.

As the steeper-graded Maira River cut back its water-parting, the drainage from the Albigna Valley would first be captured and compelled to flow westward, then that of the Val Marozzo, and, lastly, that of the Val Forno, the waters of the two last-named being chiefly responsible for the present cliff-like wall of the Maloggia.

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[1] Since writing the above, my attention has been called to a note in the Bull. Soc. Géol. France, ser. 3, vol. xxviii (1900) p. 1003, by M. W. Kilian, who, on theoretical grounds, comes to much the same conclusion as that enunciated above.

[2] A. Heim, Jahrb. d. Schweiz. Alpenclub (1879–80) p. 429; T. G. Bonney, Geol. Mag. 1888, p. 540; & C. S Du R. Preller, *ibid.* 1893, p. 448.

These three valleys, belonging as they do to the high-level Engadine drainage-system, have been left far above the deeply-cut Val Bregaglia, and their streams have not yet had time to adjust their floors to accordant slopes with that of the Maira, into which they fall by precipitous cascades.

I do not think that the overdeepening which has produced these hanging valleys at the upper end of the Val Bregaglia can by any possibility be attributed to excavation by ice; for whence did the glacier come? Obviously not from the hanging valleys themselves, or how are we to account for their truncated mouths? And there is no gathering-ground for snow in the district other than the Engadine Valley beyond the precipitous wall of the Maloggia itself, the formation of which by ice I do not think the wildest advocate of ice-erosion would suggest. We have here, then, a group of hanging valleys the uppermost of which, the Forno, is in process of formation before our eyes by river-action: these are situated at the head of a glacial cul-de-sac, and cannot therefore be attributed to the overdeepening of the main valley by ice.

The river issuing from the Albigna Glacier has cut back the gorge forming the Pian dei Buoi; but the waterfall is still very steep, and no gentler grade can be established so long as the general high level of the Albigna Valley is maintained by the presence of the glacier. And this protected valley, like the hanging valleys of the Val Ticino, again faces north-east. The Val Marozzo, on the other side of the Val Bregaglia, although its drainage was captured by the Maira after that of the Val Albigna, has no protective glacier, and has already established a more gentle slope for its gorge, and the same is the case with the Orlegna. Thus we again have the lesson enforced, that it is rivers that erode their valley-floors and glaciers that relatively protect them.

IV. Hanging Valleys of Jongri-Sikhim.

In the Jongri district of the Sikhim Himalaya we find hanging valleys of the Ticino type, which appear undoubtedly to owe their origin to river-excavation. There the original easterly drainage, initiated as a consequence of the uplift of the Kangchenjunga range, is being gradually obliterated and diverted by the direct-flowing rivers subsequently developed along the line of strike parallel to the range. These subsequent rivers, running as they do more directly to the plains than the original easterly streams, have a higher graded slope, and consequently greater erosive powers; with the result that those flowing near the centre of uplift have gradually cut their valleys back and captured, one by one, the head-waters of the original eastward-flowing streams. This is especially noticeable in the case of the Praig Chu and the Chakchurong Chu—two subsequent streams which occupy deep gorges on either side of the Jongri plateau. There can be little doubt that these streams have eaten their way back from the south, and intercepted one of the old eastward-flowing rivers, capturing its head-waters in the process: these are represented by the present hanging valleys of the Kang La and its neighbours. The drainage from these glens falls by torrents and precipitous cascades into the valley of the Chakchurong, 2000 feet below; and so abrupt is the change in level from the glens to the main valley, that the traveller is occasionally obliged to depend, in the more literal sense of the word, on the branches of the dwarf rhododendrons that clothe the precipitous ledges.

It may be asked, Why have these streams not cut down their valleys to an accordant grade with the new valley below? The answer appears to be the same as in the case of the Val Ticino: first, because there has been an epeirogenic uplift in inter-Glacial times; and, secondly, because the higher glens have been, till recently, filled with ice which has protected the valley from river-erosion.

That an upward movement of this description has taken place since the formation of the range seems well attested by the observations of the Indian geologists on the Himalayan range generally,[1] from which it would appear that this movement is still in progress. For fuller proofs of the formation of these Jongri valleys by river-erosion I must refer to my notes in the 'Geographical Journal' already published,[2] merely pointing out that here also we have the hanging valleys preserved only on the eastern flanks of the range; a fact which I would again attribute largely to their preservation by the glaciers which, till recently, filled these valleys, and still occupy the upper glens.

V. Hanging Valleys of a Different Type.

In the above descriptions I have confined myself to typical hanging valleys, produced by the overdeepening of the floor of the main valley; but I should not, on this account, wish it to be inferred that I would attribute all similar valleys to this cause. There are other types of hanging valley due to other causes than those described above. Two of these types stand out prominently, and I have met with many examples in the course of my wanderings in the Alps and Arctic regions.

The first of these is to be found bordering inland sheets of water, such as the Swiss and Italian lakes. Some of these, it may be urged, were formed contemporaneously with those described above and afterwards submerged; and it is possible that those at the Flüelen end of the Lake of the Four Cantons come under this category, and are continuations of the series in the Valley of the Reuss, of which the Erstfelder Thal is a conspicuous example. The majority, however, seem to owe their origin to a different cause, and to have originated since the lakes were in existence and, indeed, to be directly due to the presence of the waters of the lake.

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[1] 'Manual of the Geol. of India' 2nd ed. (1893) p. 485. See also W. T. Blanford, Phil. Trans. Roy. Soc. vol. cxciv B (1901) p. 335.

[2] Geogr. Journ. vol. xx (1902) p. 13.

In these occurrences we have exactly what we might expect. A stream draining the hillside that borders a lake will, of necessity, gradually deepen its bed, and at the same time cut back its head-waters—in fact, establish its curve of erosion. The possible depth of this erosion will be limited by the level of the lake, below which no erosion can take place, but, on the contrary, deposition. While the lake remains at the same level, therefore, the stream is continually engaged in flattening the grade of its valley-floor, while below the level of the lake the old steeper grade is preserved. Should the level of the lake be lowered by erosion at its exit, the contrast of slope between the portions of the lateral valley formerly above and below the lake-surface respectively, will afford all the characters of a hanging valley. If this lowering of the lake be gradual, a gorge will be established cutting back into the lateral valley, for it must always be remembered that the adjustment of two discordant valleys can only take place from below, causing the incision to travel backwards at a steep, though diminishing angle.

I would specially emphasize this law of readjustment, as it accounts for the effects of even a gradual lowering of the lake being visible for long afterwards in the tributary valleys, and also for long after the ice melted. Such a condition of things is well seen round the Italian lakes, especially the Lake of Como, as at Bellano, Menaggio, Varenna, and Argenio, and at Ostenno on the Lago di Lugano. The gorges already cut back by the readjustment are locally known as 'oridos.' Thus we have the Orido of Bellano, Orido of Ostenno, etc. In this case, then, it is not by the overdeepening of the main valley, that lateral hanging valleys and oridos are produced, but on account of its protection by the water of the lake.

The remaining type, to which I should like to allude, is also produced independently without any overdeepening of the main valley, and is only found in glaciated districts. These valleys are frequently connected with cirques, into which they merge at their upper end. They are produced in the first place by corrie-glaciers, which are gradually extended backward. A corrie-glacier of this character originates apparently in the following way:—The snow which falls in winter above the snow-line lodges more readily in the flatter portions of water-gullies formed in summer, and will tend to accumulate there, protecting the surface beneath from frost and water-action, while the rock-wall behind will continue to disintegrate, allowing more snow to accumulate each year, so that in time the flatter portion will extend backward into the hillside. In this way an upland glen filled with ice is gradually formed. I noticed many hanging glaciers of this description in Spitsbergen, and, though less common, they undoubtedly exist also in the Alps.[1]

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[1] See Quart. Journ. Geol. Soc. vol. lv (1899) pl. xliv.

VI. General Conclusions.

The questions opened up by a discussion of the origin of the hanging valleys in the Alps are very wide, but I have confined my description to those types which have been attributed to direct excavation by ice; and, in the majority of cases cited, the whole question seems to turn on the relative power of excavation possessed by ice as contrasted with water. Having lived among glaciers most of my life, and for some years past having taken the greatest interest in all problems connected with ice, I must express my firm conviction that ice, far from hastening the erosion in a valley previously occupied by a river, appears to me in every case that can be tested to retard the erosion of its floor, and may therefore even be described as a protective agent. Here I am only repeating what has often been expressed before by those best acquainted with ice and snow. Mr. D. W. Freshfield, some years ago,[1] in an admirable essay on the subject, which has been too often overlooked, summed up the question most tersely:—

> 'I believe that a careful inspection of mountain-valleys shows conclusively the very limited extent of ice-action as a quarrier or excavator. And I would urge all who consider water, as compared with ice, "the weaker agent," to measure their respective performances at Grindelwald and Rosenlaui, where between the superficially ice-abraded rocks the torrent has carved for itself a bed hundreds of feet deep. . . . We find that where a barrier presents itself to a glacier furnished with a strong subglacial torrent, the tendency of the ice is to pass over the barrier, the tendency of the water to cut through it. The one acts as sandpaper, the other as a saw. . . . So far as I can see, U-shaped valleys are not V-shaped—or trench-like—valleys broadened by ice, but V-shaped valleys are U-shaped valleys deepened by water-action.'

Here we have an exact description of what has really taken place in the Val Ticino. Prof. Heim, again, sums up in a similar manner when he remarks that 'glaciation is equivalent to relative cessation of valley-formation.'[2] It is to this cause that I would attribute the existence of the hanging valleys of the Ticino and Jongri type as described above, the lateral valleys being protected by glaciers, while the main valley was being deepened by water.

If we examine the termination of glaciers at the present day, they are seen to rest invariably on a more or less raised platform, because of the protection which they afford to the ground underneath. In the Arctic regions I have seen glaciers advancing over loose beach-material and picking it up in places, but doing no excavation; indeed, they are unable to push forward their ice-débris, and advance almost entirely by the shearing of the upper layers over those below. Take the case of the Upper Grindelwald Glacier, or any icefall, the glacier does not dig itself out a course: it simply falls over. The Rhone-Glacier icefield is, curiously enough, cited by Prof. Davis as a hanging valley due to excavation

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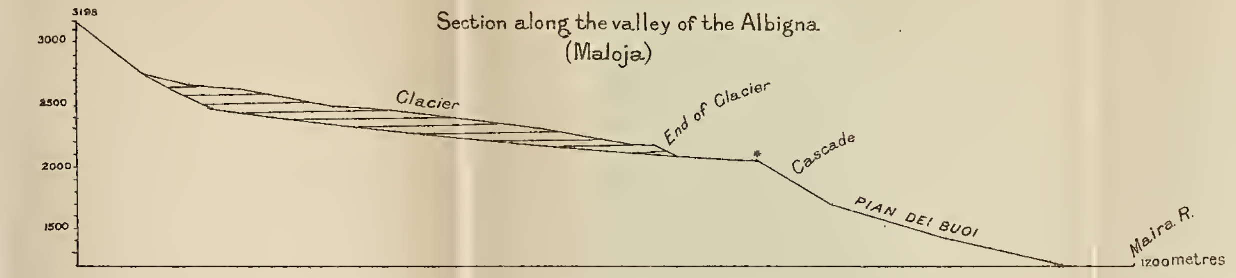
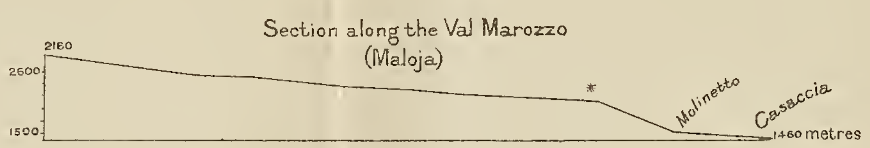
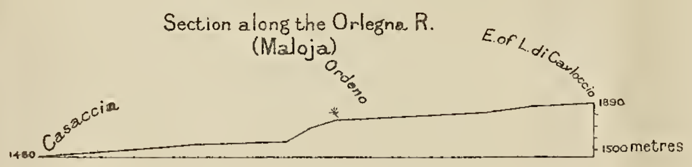
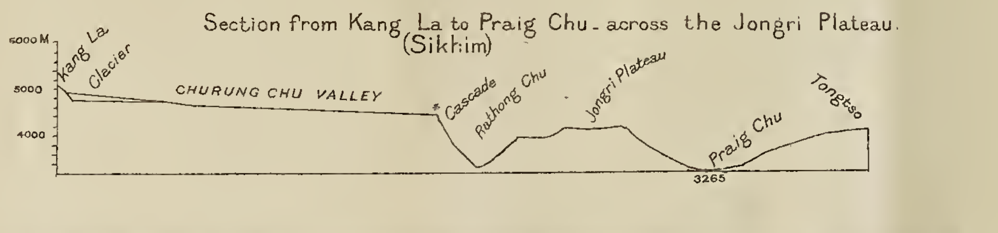
[1] 'Note on the Conservative Action of Glaciers' Proc. Roy. Geogr. Soc. vol. x (1888) pp. 785, 787.

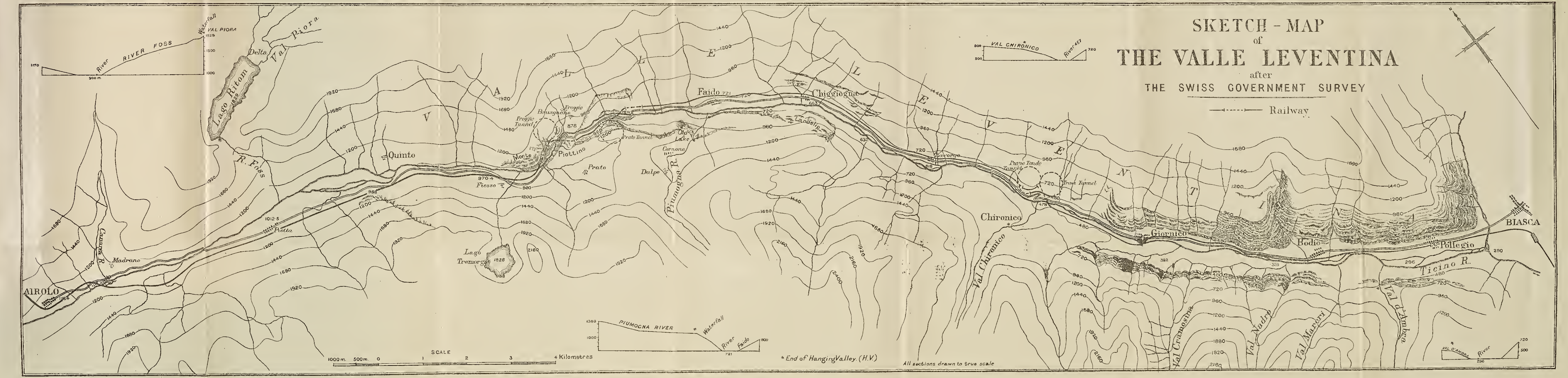
[2] 'Handbuch der Gletscherkunde' 1885, p. 397. See also T. G. Bonney, 'Do Glaciers Excavate?' Geogr. Journ. vol. i (1893) pp. 481–99.


Section along the valley of the Albigna (Maloja)


Section along the Val Marozzo (Maloja)


Section along the Orlegna R. (Maloja)

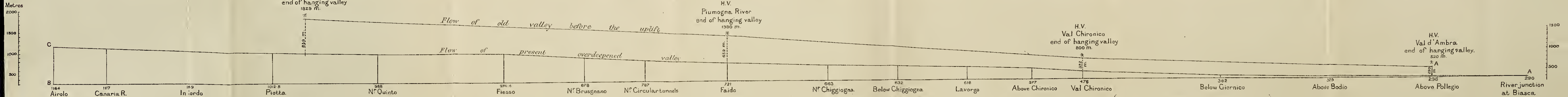

Section from Kang La to Praig Chu - across the Jongri Plateau. (Sikhim)


SKETCH - MAP of THE VALLE LEVENTINA after THE SWISS GOVERNMENT SURVEY

Railway

* End of Hanging Valley. (H.V.)

All sections drawn to true scale



LONGITUDINAL SECTION ALONG THE VALLE LEVENTINA

(All contours throughout are stated in metres)

Fig. 1.—*Gorge of Monte Piottino, from above Fiesso.*

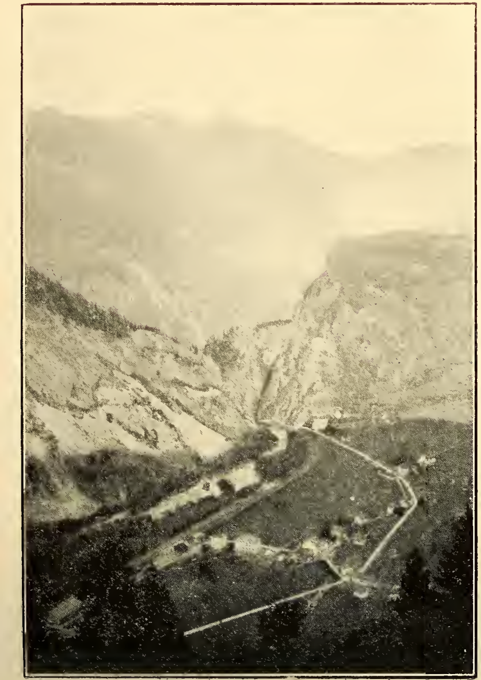
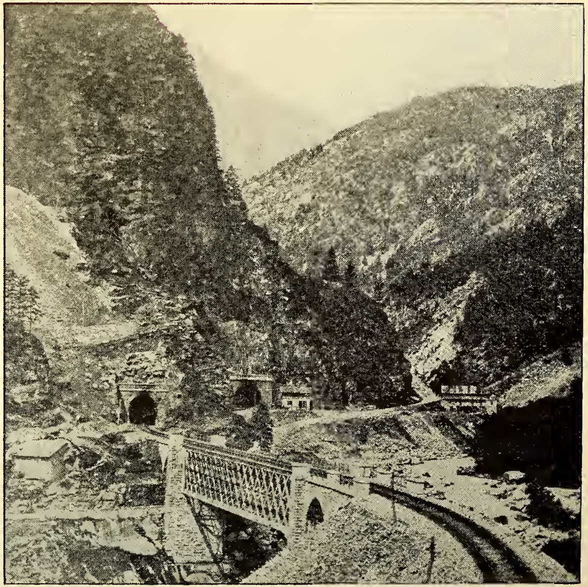
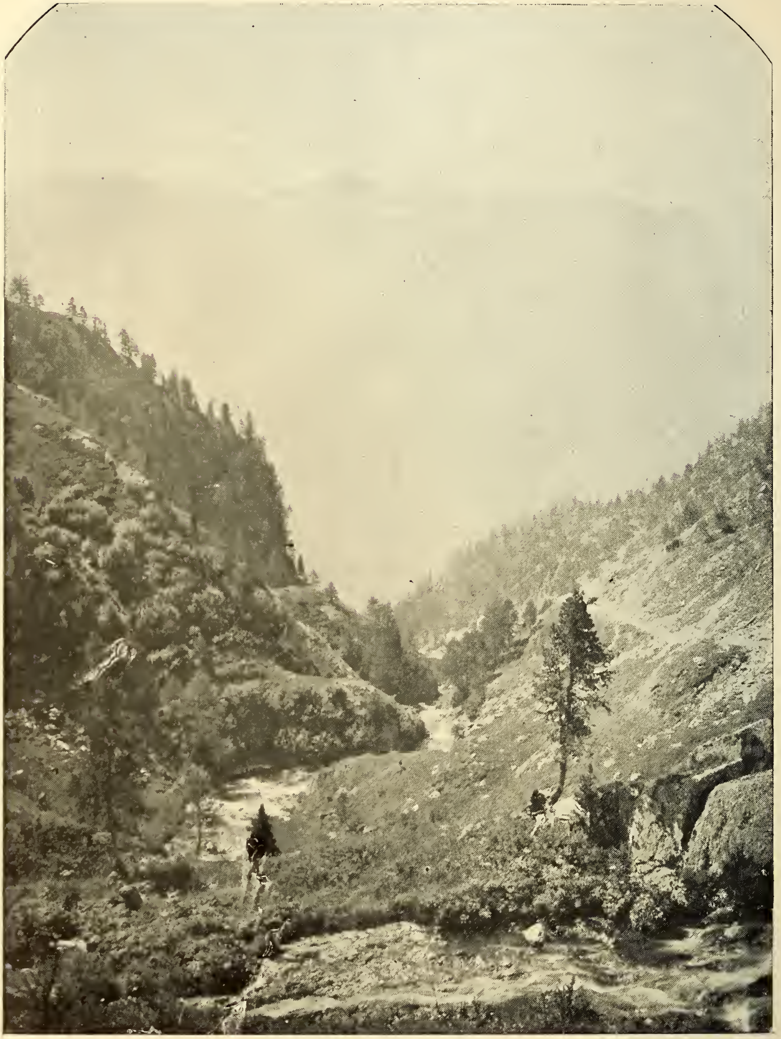


Fig. 2.—*Overlapping profiles below Faido.*





THE GORGE OF LA FOOS, FROM VAL PIORA.

by ice,[1] but the ice which formed it must have come down the valley now occupied by the icefall. Therefore, Why the icefall? Why was the barrier not degraded?

Mr. Harker, in his admirable description of the glaciation of Skye, alludes to the weight of the ice and the grinding of the ground-moraine. A great deal of excavating work has been attributed to ground-moraine; but, as a matter of fact, there is very little material at the bottom of the ice. Most of it is carried englacially in an ice-sheet, and not between the ice and the valley-floor.

In many places it is possible to study the relative action of ice and running water, occupying the same valley and working side by side. Fig. 2 in Pl. XL, for instance, which is from a photograph taken in Hornsund Bay (Spitsbergen), shows a gorge cut down by the water running under the ice, and the ice moulding itself down into the gorge. The gorges which terminate many of the glaciers of Switzerland have been thus produced; the gorge at the end of the Aletsch Glacier has been cut down by the subglacial river, and the same phenomenon is well seen at the end of the Mer de Glace and elsewhere.

The question of the excavation of lake-basins by ice I must leave to another occasion, though Prof. Davis considers that they are intimately bound up with the origin of the hanging valleys. I hope, however, to have shown that, so far as the districts described above are concerned, there is no proof that the over-deepening of the main valley, and the consequent production of 'hanging' lateral valleys, has been the result of ice-excavation, and that the marked occurrence of these valleys in glaciated districts can possibly be accounted for in quite another way.

EXPLANATION OF PLATES XXXVI-XL.

Plate XXXVI.

Map and longitudinal section of the Valle Leventina, together with sections of the chief hanging valleys to which allusion is made. The map shows the various characteristics on which emphasis is laid in the text. The sections are all drawn to the true scale of 1 : 50,000, except that across the Jongri Plateau which is on the scale of 1 : 100,000. The asterisks denote the lower terminations of the hanging valleys.

Plate XXXVII.

Fig. 1 shows the river-gorge of Monte Piottino and the old river-level above on the right, which exactly corresponds with the mouth of the Val Piumogna.

Fig. 2 illustrates the overlapping character of the profiles below Faido.

Plate XXXVIII.

Photograph of the gorge of La Foos, from the edge of the Val Piora, looking down into the Valle Leventina.

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[1] 'Glacial Erosion in France, Switzerland, & Norway' Proc. Boston Soc. Nat. Hist. vol. xxix (1900) pp. 273–322.

Plate XXXIX.

Fig. 1. The river-gorge below Airolo, with relics of the older benches.

2. View of the mouth of the Albigna Valley and waterfall, from the Maloggia.

Plate XL.

Fig. 1. The upper cascade of La Foos, draining Lago Ritom, Val Piora.

2. The end of an Arctic glacier, Hornsund (Spitsbergen), showing a hanging valley protected by ice, with water-cut gorge and subglacial water-channel, into which ice has moulded itself. This illustration shows clearly the superior erosive power of water over ice, when both occupy the same valley.

Discussion [on the two foregoing papers].

The President congratulated the Fellows upon the lucid manner in which the whole subject had been presented and discussed by Prof. Bonney, and upon the fine series of illustrative lantern-views exhibited and described by Prof. Garwood. The subject was one of such conspicuous interest from several aspects, and the phenomena apparently admitted of so many interpretations, that it was little to be wondered at that scientific opinion was so divided upon the question. It was very pleasant, however, to find that lifelong workers in the Alps like Prof. Bonney and Prof. Heim, who had so many years ago described the classic examples of the Maloja, were still fully agreed in ascribing the differential denudation which had originated the Alpine examples almost wholly to the action of running water; and at the same time to find that Prof. Garwood concurred with Dr. Reusch in ascribing many of the Norwegian examples of hanging valleys to the preservative action of ice and snow. While he himself fully agreed with Prof. Bonney that the differences in level between the main valley and these lateral valleys was a matter of differential denudation by water-action, he could hardly follow him when he carried back the date of the main valleys in which they occur to the Middle Tertiary age. The suggestion made by Prof. Garwood, that the main valley had been subsequently deepened owing to increase in erosive power due to regional tilt was, he thought, novel and very plausible. The examples of associated main and lateral 'hanging valleys' which he had himself seen both in the Alps and in Norway, had led him to the opinion, that while running water had probably accomplished the erosion of both, yet the distinction between them was in some way connected with the physical conditions of the Ice-Age. The ice possibly aided in bringing about the differential denudation, not perhaps as an eroding agent, but, as in the case of the Matterhorn, as a transporting agent—the local conditions enabling it to act here as a local remover, and there as a local preserver of disintegrated material.

Mr. Marr considered that he had hardly a right to speak upon these papers, as he knew nothing of the district described; but he had long been interested in 'hanging valleys' in the Lake District. He would like to know how Prof. Davis, in the case of certain valleys

Fig. 1.—*The river-gorge below Airolo, with relics of the older benches.*

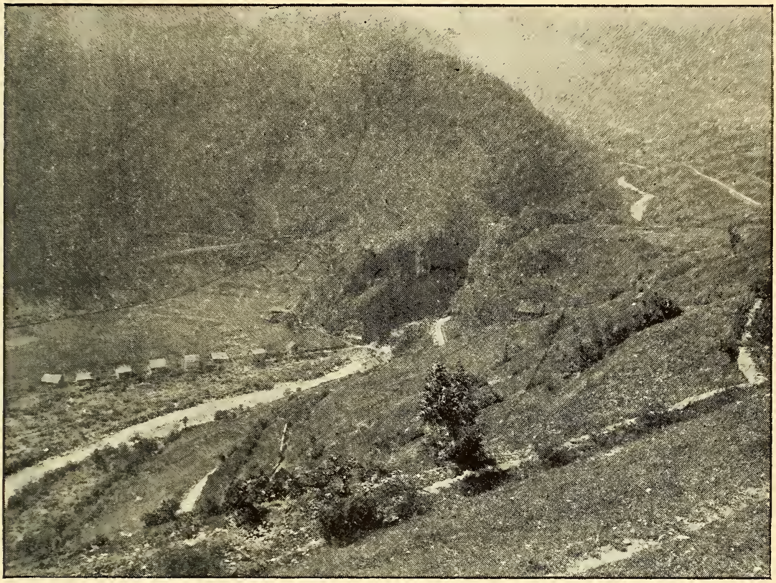


Fig. 2.—*View of the mouth of the Albigna Valley and waterfall, from the Maloggia Pass.*

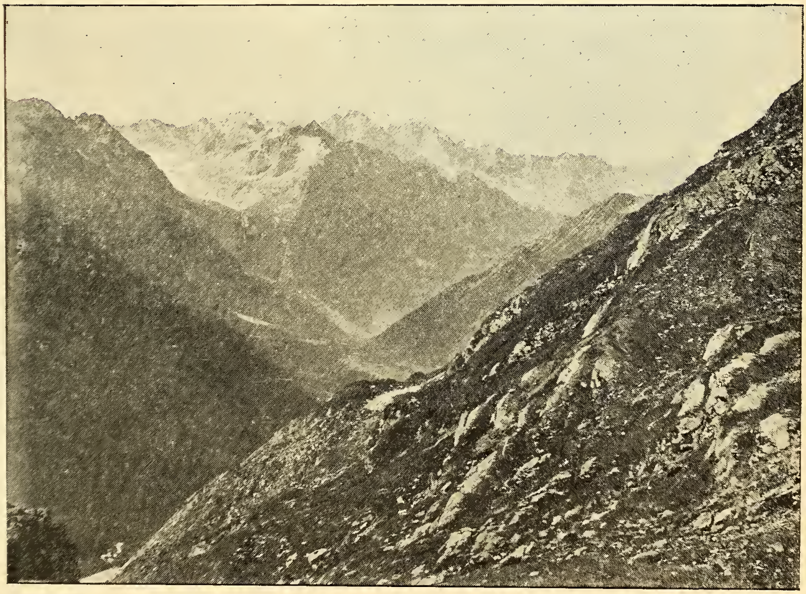


Fig. 1.—*Upper cascade of La Foos.*

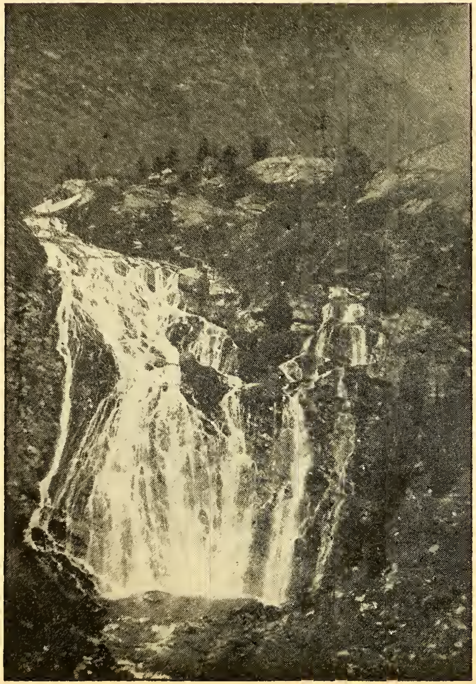
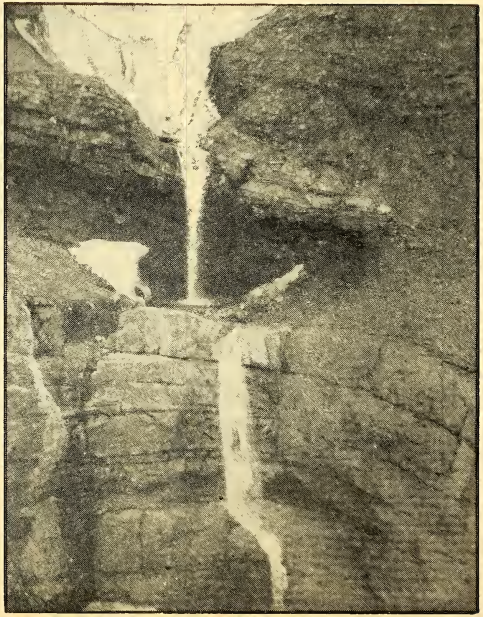


Fig. 2.—*The end of an Arctic glacier: Hornsund (Spitsbergen).*



with overlapping spurs which he had described, had ascertained that the partial destruction of the spurs was due to ice, and not to water. In the Lake District, he (the speaker) believed that the hanging valleys were often due to differences in rock-structure, especially to the existence of gigantic brecciation along the main valleys, though many other structures produced their effects. He wished to emphasize the importance of carefully studying each case (as had been done by the Authors), for many valleys which were not really 'hanging valleys' appeared, at first sight, to simulate them; and, indeed, he believed that detailed study of various different districts was necessary before the intricate question of the formation of these valleys could be finally solved.

Mr. Mackinder agreed with the previous speaker that we should first study special cases, and then generalize. But if we accept the general idea of a difference of erosive power as the cause of the contrast between the main and the 'hanging' valleys, then the hanging valleys should diminish in scale towards the upper part of the main valley, unless indeed there should be a hanging valley at the head of the main valley. Perhaps this might be so in some cases.

Mr. Lamplugh remarked that, whatever objection might be taken to the methods and conclusions of Prof. Davis, his work, at any rate, deserved credit for having stimulated fresh investigation on all sides. He agreed with Mr. Marr that hanging valleys might be formed in different ways, and therefore required separate study. In the examples best known to him, the explanation given by the present Authors, that the trunk-valleys had been deepened mainly by stream-erosion, was fully adequate. At the same time, it must not be forgotten that there were proofs that the land-surface had sometimes been pared down by ice-action, though perhaps not so much in confined valleys as in more open ground.

Gen. McMahon, as an illustration of the small power of erosion possessed by a glacier, instanced a case in the Upper Spiti Valley, in the Central Himalayas, at an elevation of 14,000 feet, of a small spur composed of thin splintery slates, running into the valley at right angles to the course of a glacier, which once filled the valley. The crest of this thin ridge was rounded, beautifully polished, and grooved and striated by ice-action, showing that the glacier had ridden over it, in its passage downward, but had been unable to remove this barrier.

Prof. Bonney, in replying, remarked that he had avoided appealing to the effect of uplift (though he was quite prepared to admit that it might have occurred), because he wished to see the results of less hypothetical causes. He fully endorsed Prof. Garwood's remarks about the Maloja and other parts of the Engadine. The President was quite right in attributing the explanation of the structure of the Inn Valley to Prof. Heim. In fact, it had been independently published by him and by the speaker, but the former had priority. He thought that the President had a little misunderstood (probably owing to his remarks about the Oberland) what he had said about the main and side valleys; he believed their formation to be simultaneous, but the main stream would be more energetic, because it was augmented by the lateral ones. Mr. Marr was quite right as to the importance of study of individual instances, but the speaker had examined a very large number, for he had been at work on such questions for fully forty years, and in the Alps the rock-masses were on a larger scale than in English hill-countries, so that explanations of lines of weakness would not so generally apply in the former as in the latter. To Mr. Mackinder, he observed that the floors of the hanging and the main valley did become nearer in going up the latter, but he could not see how a hanging valley should occur at its head, for there could not be any differential motion to cause it. To Mr. Lamplugh, he replied that inferences from the action of moving masses of ice upon a soft material were not of much value when transferred to hard rock; personally, he did not feel gratitude for papers written after hurried journeys. He had preferred to spend about ten years in examining these valleys, for he did not believe that science was benefited by hasty generalizations.

Prof. Garwood, in reply to Mr. Lamplugh, said that he had tried to avoid too much generalization on glacial erosion, as it was a large subject, and had confined his views to the four districts described in the paper. He quite agreed with him that the surfaces of upland districts were liable to have the disintegrated material removed by ice, and the solid rock grooved and polished, and he pointed out in his paper that this had happened in the Val Ticino since the overdeepening of the main valley. He thanked the Fellows for their reception of his paper.